Augmented Iterations: Integrating Neural Activity in Evolutionary Computation for Design

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Abstract. The principle of *Augmented Iterations* is to create shapes of progressively higher complexity, thanks to a fast neuronal selection of shapes among several possible evolving designs. Such a process is made possible by the use of a brain signal known as *P300*, which appears when a user perceives a rare and relevant stimulus and can be used for intricate pattern recognition and human computation systems. We aim at using this *P300* signal to identify the (re)cognition of shapes or designs that a user finds almost instantaneously relevant and noticeable, when exposed to a rapid visual flow of variations of such shapes or designs. Using evolutionary algorithms, the shapes identified as those triggering a P300 in the user's EEG signals is selected and combined to give rise to geometrical aggregations of a higher complexity. These new shapes replace the previous ones in the rapid flow of variations presented to the user, hence iterating the evolutionary design.

Keywords. Neurodesign; Generative Design; Integrated Cognition; Evolutionary Computation.

1. Introduction

Since research on **Brain Computer Interfaces** : *BCI* began in 1970s at the University of California Los Angeles and revealed the first apparition of the expression recorded in scientific literature (Vidal, 1973, 1977), the evolution of interfacing the nervous system in general or the brain specifically to a device or a computer system in order to restore or augment animal and human abilities to sense its environment, to communicate, to move into space as well as to perform cognitive tasks grew fast (Wolpaw et al, 2002). Despite the youth of the field of research, applications development have been intensive specially in developing neuroprosthetics for medical purposes at various ranges of invasiveness into the human body. In parallel to that development and the one of technologies of information and communications : *TIC*, private companies and open-source initiatives led to the popular access of even cheaper and non-invasive devices using the evolution of Electroencephalography : *EEG* and signal processing technologies. Between *Neurosky*, *eMotiv*, *openEEG*, *G.Tec* or many other companies and initiatives, the accessibility and precision of the technology led to open the capacity to create an effective loop between the neural activity of the human body and computers to other fields of research and experimentations (Lécuyer et al, 2008; van Erp et al, 2012). Along with that evolution of accessibility to both technological innovations and biological material, **a critical aspect of integration** opened to computational design. Since 2005, and the 3D mappings of brain activities realized by Marcos Novak and Mark Cohen as a spatial representation of intricate phenomenons leading to creative acts (Novak, 2005), design experiments have evolved in either the multi-dimensional representation of the neural activity as for 4D brain mapping projects (Collins and Hasegawa, 2011) or the expansion of domotic technologies and human-machine cooperations by controlling external devices to modify the physical space, as for the *CogniGame* (Festo, 2012). But as we are advancing in the comprehension of morphogenesis for generative design and the evolutive integration of ambient data into that very generation, many transitions in the process between one step to the other is yet constrained under the necessity of human cognition and empiristic phases. The cognitive task of performing a selection of satisfactory generated results is yet to be performed as a separate and complementary process in the development of a morphogenetic design and leaving an important blur between a systematized design to satisfy a predefined set of rules and constraints and the judgment/selection of a satisfactory performance. The ongoing research described hereafter intends to establish a critical and effective link between the computation of human cognition and the evolution of design models by exploiting recent advancements in neurosciences to interface and integrate the human capacity to compute cognitive selections at fast pace in an iterative and evolutionary design loop. We define as **NeuroDesign** the fluent process to compute such design models merging both human cognitive performances and machine systemic capacities in a single loop. This first definition was first experimented and challenged at the beginning of 2012 and revealed the very potential of accelerating the process toward a closer definition of a generative design model combining those two aspects by augmenting every iterations with the acquisition and treatment of a peculiar neurosignal produced by the human brain when a specific recognition is made. This last definition is called **Augmented Iterations**.

This paper is organized as follows: Section 2 gives more details about the design of a BCI and its use in the process. Then, Section 3 presents our work and experimentation on Neurodesign. Finally, Section 4 proposes the refinement of the Neurodesign definition as the current step of investigation: Augmentation Iterations.

2. Designing a BCI

BCI are communication systems that enable a user to send commands to a computer by means of brain activity only, this activity being generally measured by EEG (Wolpaw et al, 2002). A typical example of a BCI would be a system with which a user could move a cursor, on a computer screen, towards the left or right by imagining movements of the left or right hand, respectively. Designing and using a BCI consists in setting up 4 main components, illustrated in [Figure 1].

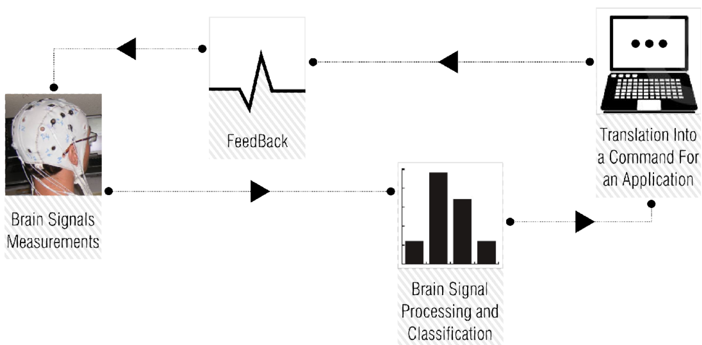

Figure 1 Operation principle of a BCI

First, the user's brain activity must be measured. To do so, most BCI systems are based on EEG, which measures small electrical current on the user's scalp reflecting the synchronous activity of millions of neurons. It should be mentioned that current EEG-based BCI technology is far from being able to (and may never be able to) identify any kind of mental states in the user's EEG signals. As such, current BCI measures the user's brain signal while he/she is involved in specific mental tasks which lead to specific EEG patterns. As an example, numerous BCI are based on *Motor Imagery*, that is they can recognize specific EEG patterns that appear when the user is imagining limb, mostly hands or feet, movements (Pfurtscheller and Neuper, 2001). Another widely used EEG pattern is known as the P300, which is a Positive increase of the EEG signal amplitude which appears 300 ms after the user perceived a rare and relevant stimulus (Donchin et al, 2000). Once the user's brain activity measured, the next step consists in analyzing and processing the measured brain signals in real-time in order to identify a specific EEG pattern, such as that corresponding to an imagined hand movement or a P300. This is achieved using advanced signal processing and machine learning algorithms whose details are outside the scope of this paper. Interesting readers could refer to : Lotte et al (2007) and : Bashashati et al (2007) for details on these aspects. One point must be mentioned though: in order to identify a given user's EEG patterns, the BCI system must be calibrated specifically for this user since there are currently no one-size-fit-all universal BCI. This is achieved thanks to several examples of EEG signals of this given user, collected while he/she performs the targeted mental tasks. In practice, this means that before using a BCI, the user must first participate to a calibration session during which examples of his/her EEG signals will be collected.

Once the EEG signals measured, processed and identified, we can assign a given command to the recognized EEG pattern. For instance, we could associate a recognized imagined left hand movement to moving the cursor towards the left, whereas an imagined right hand movement will be associated to a cursor movement towards the right. Finally, the loop can be closed by providing a feedback to the user, in order to let him know which EEG pattern the system has recognized. This will help the user to learn how to use the BCI, as well as help him/her to improve his/her control over his/her own brain activity. Indeed, BCI control can be seen as a skill, which improves with practice. In other words, the more the user performs a given mental task, the better at it he/she will become and the clearer the EEG patterns will be. Overall, this will make the recognition performance of the whole system better. Because they do not rely on any actual motor activity, BCI have quickly become a promising device for people suffering from severe paralysis, since they offer them a unique alternative way to communicate (Birbaumer et al, 2000). More recently, the application scope of BCI have even widen, with several new fields benefiting from BCI technologies for healthy users, such as video games, virtual reality, human-computer interaction, cognitive monitoring or neuromarketing (Lécuyer et al, 2008) and (Van Erp et al, 2012). In this paper, we propose and explore a new application area for BCI: Neurodesign.

3. **Experimenting Neurodesign**

As mentioned previously, BCI brings together **a capacity to merge both human and computer performances for cognition and calculus**. It operates as a heuristic graft in the evolution of a systemic design to seek novel solutions not only based on optimal performances but also on the augmentation of process iterations by the continuous cognition of what was preceding a current generation to define the following generation. This particular notion of the ***Following Generation*** as developed by : Malabou (2005) is here understood as a critical point to underline a different understanding of generative design where the filiation of one generation after another is more than, and also different from, the very linear parent-children one. Therefore, ruled-based design implemented in such a system to evolve does not only represent spatial optimums but an **intricate resolution of computational aesthetics**.

3.1. *Proof of Concept*

To experiment such a definition we first organized an inter-semester workshop which have been taking place in an architectural school in February 2012 and composed of a mixed range of twenty architecture students. The general focus of this event was to experiment logical associations and formal dissociation between algorithmic, geometry, and related neural activity. On the one hand, the challenge of such a synthetic approach was on the definition and effective use of an appropriate and stable BCI and on the other, to develop methods of conception based on **systematic processes of form generation and cognition**. The evolution of this workshop has then be constrained by the implementation of an interface, the development of generative models and their association within the following framework for evaluating the very first results of this initiative and identifying their potentials for an ongoing research described hereafter. More precisely, the experiment was divided between the setup of the BCI, the acquisition of brain signals, the analysis of those signals and the development of generative models as an integrative design loop to act on virtual models without physical movements [Figure 2]. Other aspects of the implementation of such a loop will be mentioned as the signal processing, classification (pattern recognition), translation into a command and the perceptive feedback or *Neurofeedback*.

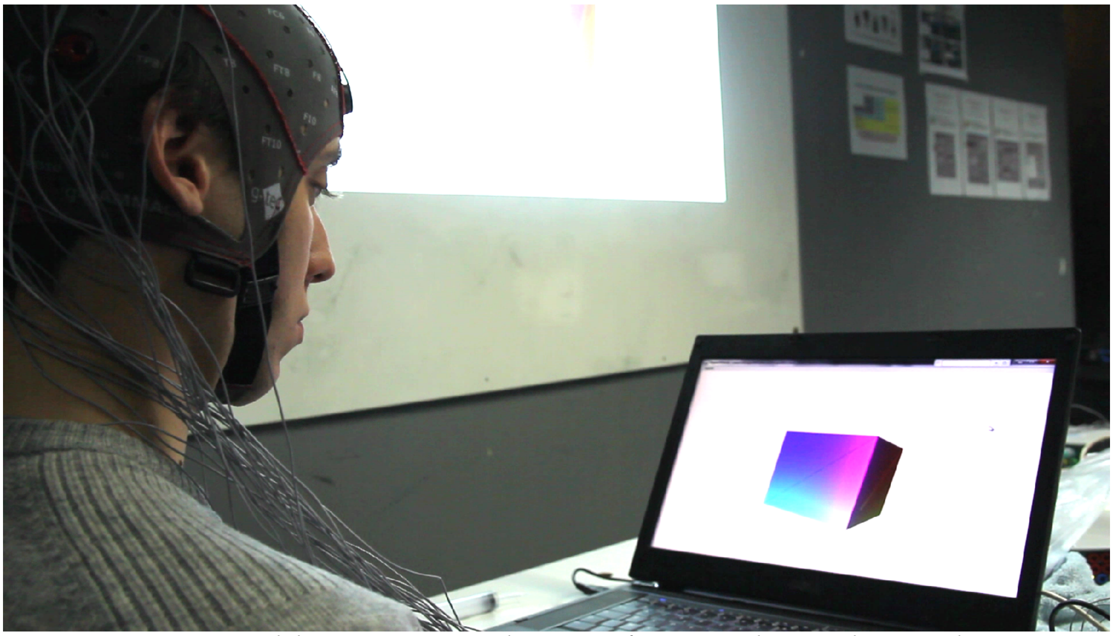

Figure 2 First workshop, a participant in the process of moving a cube in a 3 dimensional space.

3.2. *Hardware / Software*

The BCI was physically formed of a non-invasive BCI. More precisely, brain signals were measured using the *g.USBamp EEG* device (G.Tec, Austria), with 15 EEG sensors, localized at the standard positions *Fz, FC3, FCz, FC4, C5, C3, C1, Cz, C2, C4, C6, CP3, CPz, CP4, Pz* [FIGURE 3]. These electrodes are indeed localized over the motor cortex areas of the brain, and as such ideal to identify imagined movements of hands or feet. EEG signal processing and the neurodesign application ran both on the same standard laptop computer.

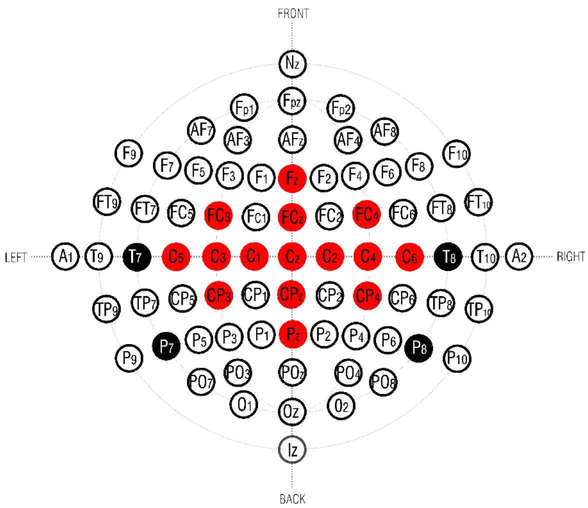

Figure 3 Standard localisation of EEG sensors. The head is seen here from the top, the nose facing upwards. Electrodes used in the Neurodesign experiment are indicated in red color.

In the objective to make **an accessible design experiment** from this research in the future, all software used are both open-source and free to use. The acquisition and exploitation of brain signals has been made possible by the use of *OpenViBE* [1] a software platform used for the design, test and use of BCI (Renard et al, 2010). It features the real-time processing of brain signals and can be used to acquire, filter, process, classify and visualize such signals in real-time. OpenViBE was used here to digitally acquire EEG signals, process them and identify imagined limb movements (left hand, right hand or foot movements) in real-time. To distinguish imagined left hand movements from imagined right hand movements, a standard algorithm was used, based on *Common Spatial Pattern* (Blankertz et al, 2008) and *Support Vector Machine* (Lotte et al, 2007). Imagined foot movements were identified as described in : Lotte et al (2008). Once the mental state of the user identify, this state was sent to *Processing* [2], a popular software used to teach fundamentals of computer programming in a visual context and allows for quick assertion in design experiments. Processing was used simultaneously to the set-up of the hardware and calibrations to teach students how to transform an architectural or design model into a graphical programming model. Both softwares allowed to progressively bring the notions of systemic design and shape generation to students while trying to translate ruled-based design into lines of code. Finally, The Processing and OpenViBE softwares were connected using the *VRPN* protocol [3]. This enables Processing to receive mental commands identified in EEG signals and sent by OpenViBE at a fast pace. Ultimately, the stable results of these applications will be compiled and made accessible through a web base application at the end of this first research [4].

3.3. *Refining Definition*

Beyond technical improvements in signal acquisition and analysis as well as translations into the design model, this first experiment allowed us to refine and extend the previous definition of Neurodesign. If such an interface can be validated to integrate a design process, it doesn't improve it by any means or bring novelty to the evolution of a geometrical model. The only powerful aspect of this definition would be to bring injured or physically handicapped people new creative means. But imagined limb movements could never surpass a real movement as would do a simple click on a mouse to move a virtual object from one place to another. Therefore it was not the human computation of movements in space that we would integrate anymore but **the very neural reaction to a change of state in a particular model or shape**. The synaptic efficiency to compute the cognition of intricate psycho-physiological events in reaction to an environmental change would be a more promising resource to integrate in terms of immediacy of response and emergence of novelty.

4. Implementing Augmented Iterations

The general idea behind the augmented iteration Neurodesign concept is to create shapes of progressively higher complexity, thanks to a fast neuronal selection of shapes among several possible designs and the use of evolutionary algorithms. To do so, we plan to use the brain signal known as the P300, which appears when a user perceives a rare and relevant stimulus and can be used for intricate pattern recognition and human computation systems. We aim at using this P300 to identify the (re)cognition of shapes or designs that a user finds almost instantaneously relevant and noticeable, when exposed to a rapid visual flow of variations of such shapes or designs. Using evolutionary algorithms, the shapes identified as those triggering a P300 in the user's EEG signals will be selected and combined to give rise to **geometrical aggregations of a higher complexity**. These new shapes will replace the previous ones in the rapid flow of variations presented to the user, hence iterating the evolutionary design [Figure 4].

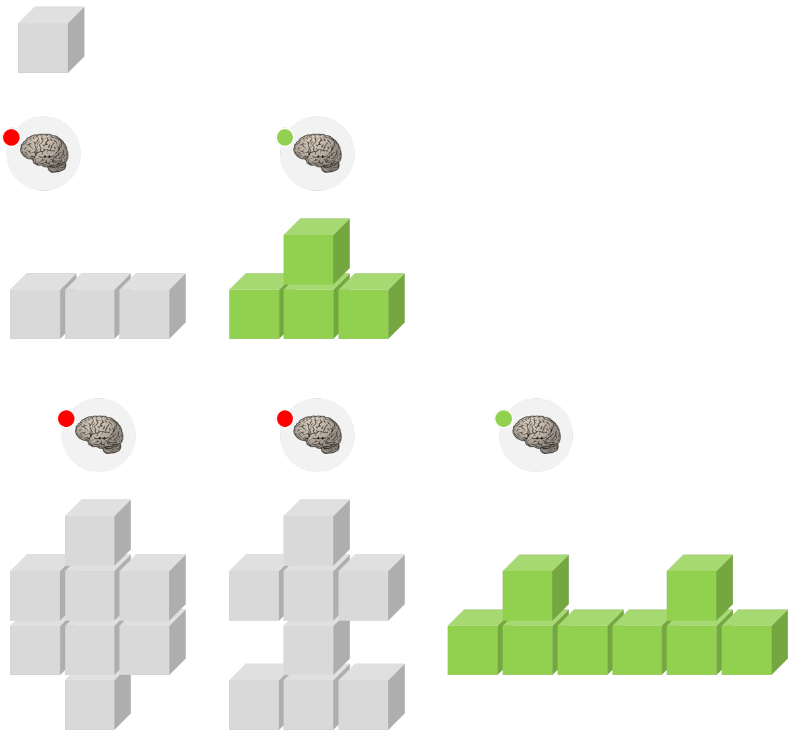

Figure 4 Graphical explanation of an iterative model selecting shapes by the recognition of a P300 signal.

In order to be more specific, here follows how we envision this application: the user will be sitting in front of screen, wearing an EEG cap (see following section Hardware / Software interface for electrodes location) connected to the computer. This user will be presented with a rapid visual flow of different shapes (that would mostly be variations of a given shape). Each shape will appear several times in the flow of images. This user will be instructed to pay attention to this shape and to concentrate on the most relevant and aesthetics according to him. While the user is watching the visual flow of shapes on screen, his/her EEG signals will be collected and analyzed in real-time. Each time a shape is displayed on screen, a BCI will be used to identify whether this shape triggers a P300 in the user's brain activity. If it does, it probably means that the user consciously or unconsciously finds this shape relevant in some way. As such, the amplitude of the P300 or the number of times the P300 appears for a given shapes gives use a *Fitness Score*, indicating how **cognitively relevant** this shape is for the user. Once each shape has been presented a given number of time, we can mark them with the Fitness Score described above. This score will be used to select and combine these shapes into several aggregations of shapes of higher complexity. These new shapes will then replace the previous shape in the rapid flow of visual shapes, and the process will iterate (i.e., the process will start again at step 1, using these new shapes). In this way, several shapes of increasingly complex design and hopefully increasingly more relevant will be created, based on the cognitive response (the P300) of the user.

4.1. Hardware / Software

For this system as well, it would be appropriate to collect EEG signals using the g.USBAmp. However, since we aim at recognizing a different brain signal, here the P300, different sensor locations should be used. More precisely, sensors located in positions Fz, Cz, P3, Pz, P4, PO7, PO8 and Oz would be more appropriate [Figure 5], since the P300 is expected to occur in these locations. A standard laptop would still be enough to run the EEG processing and neurodesign applications.

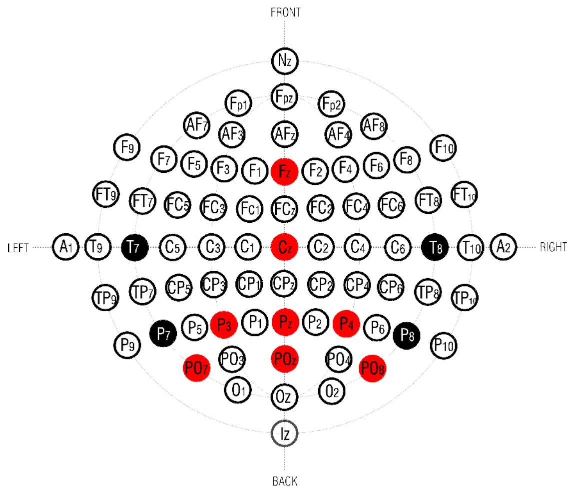

Figure 5 Location of sensors that are relevant to identify a P300 in EEG signals, and that would use for augmented iterations neurodesign.

Here again, combining OpenViBE for BCI design with Processing for shape generation, display and iteration would still be ideal. Concerning EEG signal processing, recognizing the P300 in EEG signals could be achieved using dedicated algorithms already available in OpenViBE, such as *xDAWN*, see, e.g. : Congedo et al (2011) and : Rivet et al (2009).

4.2. Current Design Experiment

By developing and refining the previous definition of Neurodesign to seek a working model of Augmented Iterations we found an efficient combination to explore: the implementation of an evolutionary ruled-based design model merging with the human computation of intricate change of state in an evolutive shape by the cognition of environmental information existing beyond geometry or the rules defining the model itself. The framework and the process defined in that paper explains the development of the reflexion leading to the current state of this research and propose new opportunities to investigate the potential emergence of novelty in generative design. The current process of design experiment aims at extending and refining this actual definition. By using previously established knowledge and experience we developed a peculiar generative model which detailed description goes beyond the scope of this paper but will be briefly introduced. We chose to first develop models which could create *smooth* and *generic* geometries in order to enable more freely cognitive reactions without sticking instantly recognizable common shapes or geometries. Therefore, as a starting point, we implemented an isosurface enveloping an evolving set of particles in four dimensions. This envelope being rendered as a mesh and visually enriched by custom shaders. The role of these custom shaders are here precisely to augment the difficulty of instant visual recognition of shapes by the human brain and stimulates cognitive performances at a higher level [FIGURE 6].

Figure 6 Current experiment in generative design using the principle of augmented iterations with isosurfaces, particle systems and custom shaders.

To prevent a recognition of a certain repeatability, each iteration of the model is set in a constant and random 3d rotation as well as the random movement of the particles making the shape grow. Generation after generation, the model evolves along the very protocol defined above and express a generative principle at a stochastic level that only a human-computation system can process [FIGURE 7].

Figure 7 Generation samples of the current model of experimentation.From left to right and top to bottom: generation 10, generation 20, generation 50 and generation 80.

References

A. BASHASHATI, M. FATOURECHI, R.K. WARD, G.E. BIRCH, “A Survey of Signal Processing Algorithms in Brain-Computer Interfaces Based on Electrical Brain Signals”, Journal of Neural engineering, 4, R35-57, 2007

N. BIRBAUMER, A. KÜBLER, N. CHANAYIM, T. HINTERBERGER, J. PERELMOUTER, J. KAISER, I. IVERSEN, B. KOTCHOUBEY, N. NEUMANN, H. FLOR, “The Thought Translation Device (TTD) for completely paralyzed patients”, IEEE Transactions on Rehabilitation Engineering, vol. 8, pp. 190-193, 2000

B. BLANKERTZ, R. TOMIOKA, S. LEMM, M. KAWANABE, K.-R. MÜLLER, “Optimizing spatial filters for robust EEG single-trial analysis”, IEEE Signal Proc Magazine, vol. 25, pp. 41-56, 2008

M. CONGEDO, M. GOYAT, N. TARRIN, L. VARNET, B. RIVET, G. IONESCU, N. JRAD, R. PHLYPO, M. ACQUADRO, C. JUTTEN, “‘Brain Invaders’: a prototype of an open-source P300-based video game working with the OpenViBE platform”, 5th International BCI Conference, 2011

E. DONCHIN, K. SPENCER, R. WIJENSINGHE, “The mental prosthesis: assessing the speed of a P300-based brain-computer interface”, IEEE Transactions on Rehabilitation Engineering, vol. 8, pp. 174-179, 2000

A. LECUYER, F. LOTTE, R. REILLY, R. LEEB, M. HIROSE, M. SLATER, “Brain-Computer Interfaces, Virtual Reality, and Videogames”, IEEE Computer, vol. 41, no. 10, pp 66-72, 2008

F. LOTTE, M. CONGEDO, A. LECUYER, F. LAMARCHE, B. ARNALDI, "A Review of Classification Algorithms for EEG-based Brain-Computer Interfaces", Journal of Neural Engineering, 4, R1-R13, 2007

F. LOTTE, Y. RENARD, A. LECUYER, "Self-paced Brain-Computer Interaction with Virtual Worlds: a Quantitative and Qualitative Study 'Out of the Lab'", 4th International Brain-Computer Interface Workshop, pp. 373-378, 2008

G. PFURTSCHELLER, C. NEUPER, “Motor Imagery and Direct Brain-Computer Communication”, proceedings of the IEEE, vol. 89, pp. 1123-1134, 2001

Y. RENARD, F. LOTTE, G. GIBERT, M. CONGEDO, E. MABY, V. DELANNOY, O. BERTRAND, A. LECUYER, “OpenViBE: An Open-Source Software Platform to Design, Test and Use Brain-Computer Interfaces in Real and Virtual Environments”, Presence: teleoperators and virtual environments, vol. 19, no. 1, pp. 35-53, 2010

B. RIVET, A. SOULOUMIAC, V. ATTINA, G. GIBERT, “xDAWN Algorithm to Enhance Evoked Potentials: Application to Brain Computer Interface”, IEEE

Transactions on Biomedical Engineering, vol. 56, pp. 2035-2043, 2009

J. VAN ERP, F. LOTTE, M. TANGERMANN, "Brain-Computer Interfaces: Beyond Medical Applications", IEEE Computer, vol. 45, no. 4, pp. 26-34, 2012

J. WOLPAW, N. BIRBAUMER, D. MC FARLAND, G. PFURTSCHELLER, T. VAUGHAN, "Brain-computer interfaces for communication and control", Clinical Neurophysiology, 113, 767-791, 2002

J. VIDAL, “Toward direct brain-computer communication, Annual review of biophysics and bioengineering 2: 157-80”, 1973, and “Real-Time Detection of Brain Events in EEG”, IEEE Proceedings 65: 633-641, 1977.

M. COLLINS, T. HASEGAWA, “NYC Neural Cartography Project”, Lincoln Center Campus, Hearst Plaza, Brain-Wave data associated with 3D geometry, GSAPP Cloud Lab, Proxy: http://www.thecloudlab.org/bci.html. ,2010

M. NOVAK, “Alloaesthetics and Neuroaesthetics: Travels Through Phenomenology and Neurophysiology”, Journal of Neuroaesthetics Theory 4, July 2005, Conference of Neuroaesthetics, Goldsmith University, London, United Kingdom.

FESTO AG & Co. KG, “Cognigame, New Operational Concepts for Human-Machine Interaction”, W. STOLL, M. FISCHER, N. KÄRCHER, E. KNUBBEN, M. GEHRING, C. MANGLER, Festo AG & Co. KG; A. GHARABAGHI, F. GRIMM, G. NAROS, Centre for Integrative Neuroscience of the Tübingen University Hospital, 2012.

C. MALABOU, “La génération d’après,” Fresh Théorie, Paris, Léo Scheer, 2005.

URL:
[1] *http://openvibe.inria.fr/*
[2] *http://processing.org/*
[3] *http://www.cs.unc.edu/Research/vrpn/*
[4] *http://www.compmonks.com*